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USERS MANUAL

THOR INSTRUMENTATION DATA PROCESSING PROGRAM

Version 2.0 (Windows)

TRAUMA ASSESSMENT DEVICE DEVELOPMENT PROGRAM

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1. Introduction

The program **THORTEST** is used to process the instrumentation data acquired during a test with Thor. Data from the following sensor systems are processed by this program :

1. CRUX system in the thorax
2. DGSP system in the lower abdomen
3. Head/Neck load instrumentation systems
4. Lower Leg/Ankle instrumentation

The program can be used to calculate the following information :

1. The X, Y and Z components of the chest compression. For details, see Section 5.3.

2. The X, Y and Z components of the compression of the lower abdomen. For details, see Section 5.4.

3. Moments and loads at the Occipital Condyle (OC) joint. For details, see Section 5.5.

4. Moments at the ankle and subtalar joints. For details, see Section 5.6.

The program is a Windows program, and will run under Windows 9X/2000/ME.

1.1 Coordinate System Used

The coordinate system is defined with respect to the dummy and the axes are defined as:

Positive X - axis:	points in the anterior (forward) direction
Positive Y - axis:	points to the right
Positive Z - axis:	points in the inferior (downward) direction.

All sensor data used as input to this program should be follow the polarities defined by SAE J1733 coordinate system. All output (e.g. deflections of the thorax and abdomen) are also according to J1733.

1.2 Conventions Used in the Manual

Standard Windows conventions for selecting menu items and for selecting and/or entering file names are used. The following sections describe the operation of the program and the different user inputs that are required.

2. Files Used by the Program

Figure 2.1 illustrates the data flow path when THORTEST.EXE is run.

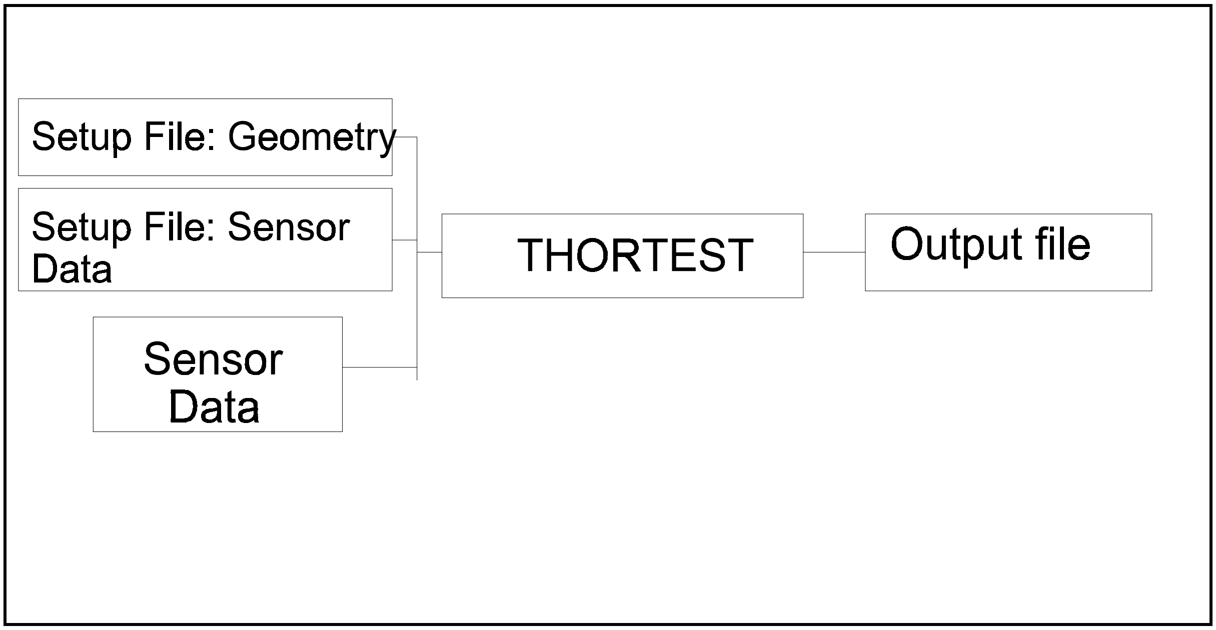

Figure 2.1 Data flow through THORTEST.EXE

Data contained in the input and output files is described below.

Table 2.1 Data contained in files used or created by Thortest.exe

File (Default name)	**Type (Format)**	**Data Description**
Setup: Geometry (thorsensor.set)	Input (ASCII)	**This file contains geometry information for the particular CRUX, DGSP, Neck Load Cell, and Ankle Instrumentation on the dummy purchased.** No data in this file is to be changed by the user. **For details see Section 8**
Setup: Sensor Data (thortest.inp)	Input (ASCII)	Information needed for data processing such as the column number in the sensor data file, filter to be used, etc. **For details, see Section 5**
Sensor data files	Input (ASCII)	Information recorded from sensors during the test. **For details, see Section 6**
Processed data files	Output (ASCII)	Processed data, e.g. chest deflections, abdomen deflections, etc. **For details, see Section 7.**

File (Default name)	Type (Format)	Data Description
Report file (thortest.rpt)	Output (ASCII)	Summary of data in the Thortest.inp if requested. **For details, see Section 40**

The names **thortest.inp** and **thortest.rpt** are default names for these files. These names can be changed to suit the users' convenience.

The operation of the THORTEST program is described in the Section 4. Section 5, 6 and 7 contain description of the structure of **thortest.inp** file, sensor data files and the processed data files, respectively.

3. Program Installation

The THORTEST program is normally supplied on a floppy disk or CD-ROM. The program is most efficiently installed on a separate directory, but can be installed in an existing directory. It does not change the Windows registry, so it can be removed by simply deleting the associated files. The files that are required to be present are:

1. THORTEST.EXE - executable program
2. thorsensor.set - sensor geometry data (usually not changed)
3. thorlogo.bmp - bitmap file used during initial loading

All other files are supplied by the user. The sensor setup file (**default name: thortest.inp**) has to be defined by the user, though sample input files are supplied with the program.

4. Program Execution

Once the program is installed, the program can be executed by using the **Run** menu item from the **Start** menu, or by creating a shortcut to the program using the normal Windows procedures. Then the program can be executed by simply clicking on the shortcut icon.

The main screen of the program is shown in Figure 4.1. The program has two menu items on the menu bar:

-File - to enter name of sensor setup file
-Process - to process the sensor data for one of the instrumentation groups

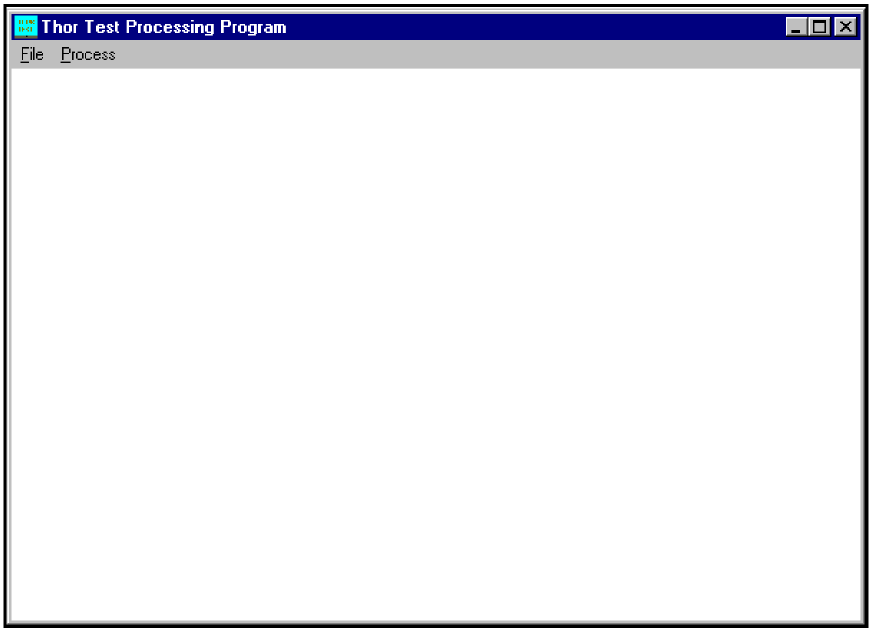

Figure 4.1 Main menu for THORTEST program.

After the screen with the main menu bar is displayed, a standard Windows dialog box for selecting the Setup Geometry File is immediately displayed. This is shown in the figure below.

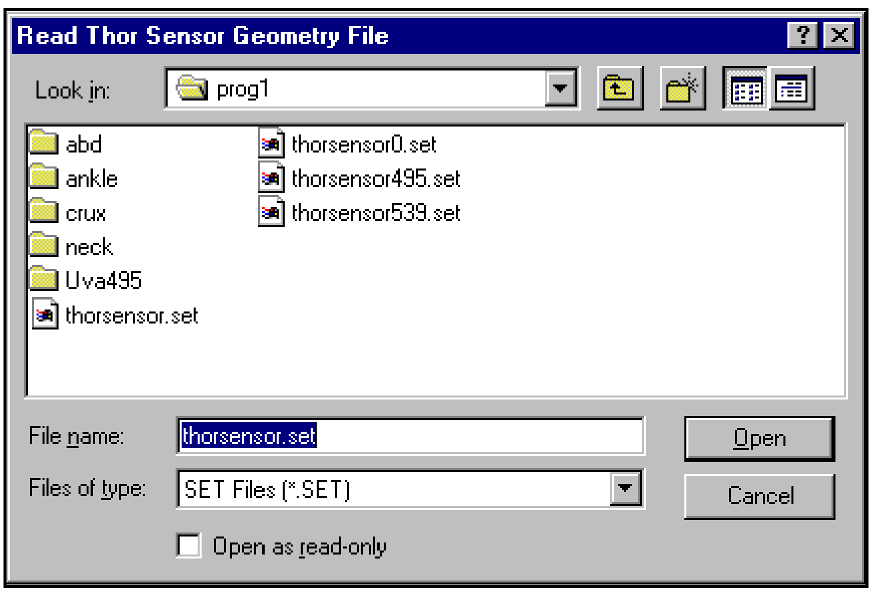

Figure 4.2 Dialog box for selecting the Thor Geometry Setup file.

The geometry file normally has an extension of ***.set**. The default name for the file is **thorsensor.set**. As indicated in Section 2, this file is defined for a specific set of instrumentation that is supplied by the manufacturer with a Thor dummy. When a sensor is replaced, the file has to be usually updated. If the default file is used, the user simply presses the **Open** button and continues to the next step. But the dialog box gives the user an option to select a different geometry file if the situation arises. In this case, select file using the mouse or enter the name of the file in the edit box. If the setup file is not found, message indicating the file cannot be found is shown. If the user leaves the dialog box without entering a valid file name, then the dialog box will again be encountered when the user tries to read in the sensor setup file as described below.

Once the geometry file is read in, the second setup file, namely, the sensor setup file is entered using the **File** menu item from the menu bar. The user selects the menu item: **Open Setup File**

Again, the standard Windows dialog box for selecting files is presented, as shown in Figure 4.3.

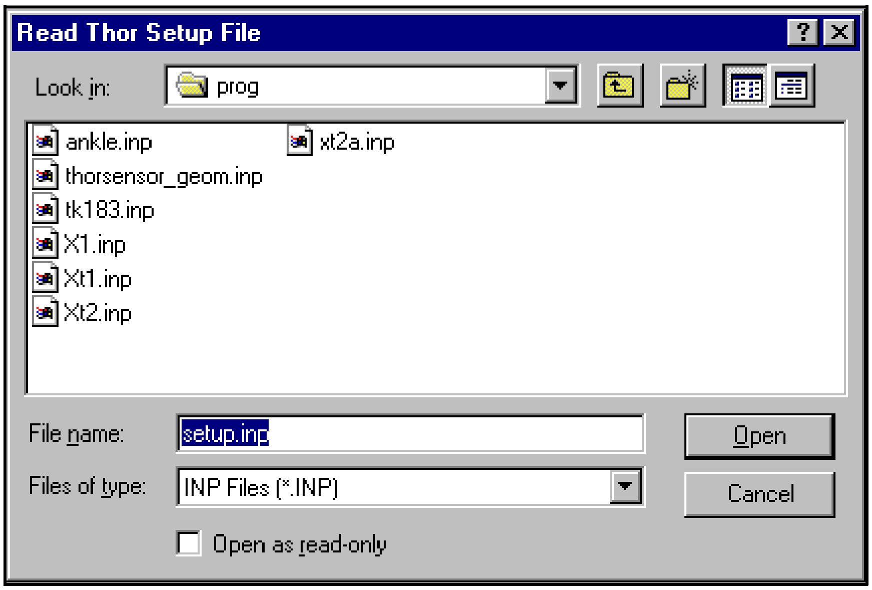

Figure 4.3 Dialog box for selecting the Thor Sensor Setup file.

Select file using the mouse or enter the name of the file in the edit box. If the setup file is not found, message indicating the file cannot be found is shown. If the user leaves the dialog box without entering a valid file name, then further processing cannot be performed. User can change the file type by clicking the drop-down list in the **Files of type:** field. The user can then select ***.* (All Files)** as the file type and allows the user to see all files and select from them. This allows one to select a file with a file extension that is not **.inp.**

The default name of the report file that is generated which echoes the data in the input files is THORTEST.RPT. The user can change the default name by using the **New Report File** menu item in the **File** menu. The user can change the name of the report file whenever the main menu bar is available.

After the setup file is read, the user should select the **Process** menu item from the main menu, to perform processing of specific instrumentation. The following menu options are available when the **Process** item is selected.

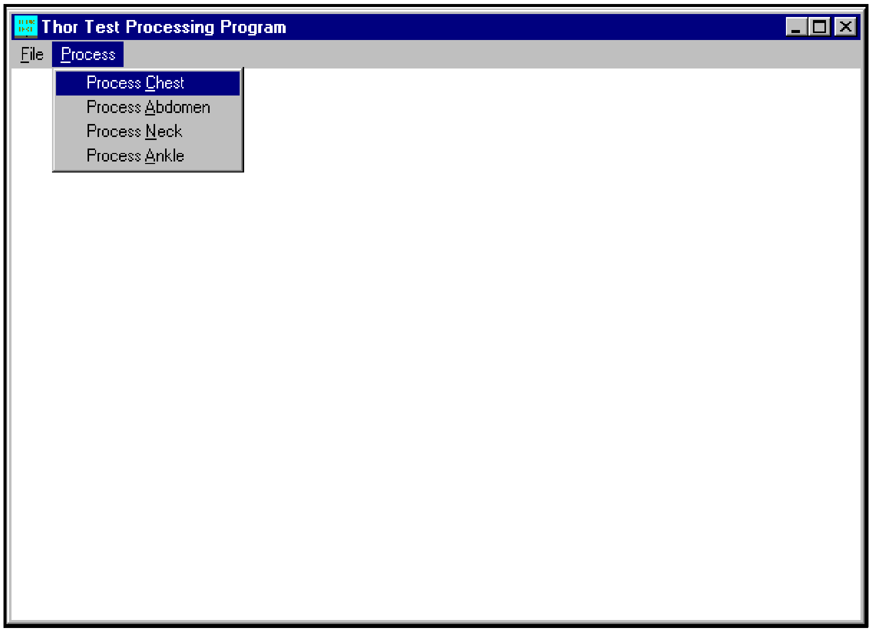

Figure 4.3 Elements of the Process Menu

The options allow the user to process the CRUX data, the abdomen data, the head/neck load data, and the ankle data.

When one of the above items has been selected, the program will normally prompt for the name of the input data file (see Section CRUX Input File Format for an example). A file selection dialog box will be displayed (similar to Figure 4.2). The user should select the directory and file from the displayed file names.

If the data file is found, then the program will prompt for the output file name, using another file dialog box. The file will contain the output processed by one of the processing routines. The default name for the output file is displayed in the edit box. The default name uses the first part of the file name and attaches a standard extension for each instrumentation group. The standard extensions are:

Crux	-	*.CRX
DGSP	-	*.ABD
Neck	-	*.NCK
Ankle	-	*.ANK

The user can simply use the default name displayed or edit it to enter a new name.

Once the specified processing is complete, then the program returns to the main menu bar (Figure 4.1). The user can process more data or exit. To exit, the user selects the **Exit** option of the **File** menu in the main menu bar.

NOTE:	**If the user has defined individual sensor data files for each of the sensor channels, then, the initial dialog box asking for the input data file name will not be displayed. The user will only see the dialog box for entering the name of the output file that will be saved.**

The format and contents of the Sensor Setup file is discussed in the next section.

5. Format and Contents of the Setup Files

The two Setup files are free format files. One contains data describing the geometry, calibration constants and other data applicable to the CRUX or DGSP in the dummy purchased. No information in this file needs to be changed unless the relevant instrumentation are damaged and replaced or the instruments are recalibrated.

The second Setup file for the sensor data contains five groups of information. The name of these groups and the information contained in each of the groups is shown below in Table 5.1.

Table 5.1 Information contained in the Setup file

Group Name	Information contained in the Group
General	Describes data related to the general structure of the data file, e.g. time step, number of channels, etc. **See Section 5.2 for details**
CRUX	Parameters related to the chest instrumentation. **See Section 5.3 for details.** Please note that the file **thorsensor.set** supplied with Thor contains all the CRUX geometry information.
DGSP	Parameters related to the abdomen instrumentation. **See Section 5.4 for details**. Please note that the file **thorsensor.set** file supplied with Thor contains all the DGSP related information.
Neck	Parameters related to the head/neck load instrumentation. **See Section 5.5 for details**. Please note that the file **thorsensor.set** file supplied with Thor contains all the neck related information.
Ankle	Parameters related to the lower leg/ankle instrumentation. **See Section 5.6 for details.** Please note that the file **thorsensor.set** file supplied with Thor contains all the ankle related information.

5.1 Data Entry Conventions

1. Each block of data is introduced by a specific block identifier. The main identifiers that are used in the input files are:

[General]
[Crux]
[DGSP]
[Neck]
[Ankle]

Following an identifier, additional identifiers may be required, finally followed by a set of parameter values.

2. Various parameters are defined with in each data block in the following format :

   parameter = *value*

   where:

   parameter = name of a specific data parameter
   value = user defined value of parameter

3. All data in the file, including names of groups or parameters is case insensitive. For example "*Time Step", "TIME STEP", "time step", and "tiME sTep*" are all equivalent.

4. Multiple parameters can be defined on a single line. Parameters should be separate by a semi-colon (;). For example the following data are valid:

   Time Step = .0001; Time Scale = 1000.; Time Unit = msec;

5. Comment lines and blank lines can be entered at any location to make the data more comprehensible. Comment lines should begin with any of the following four characters :
   ! or **;** or **C** or **c** or *****.

6. Comments can be added at the end of line containing data parameters by inserting the character **!**. Example is shown below :

   Time Step = .0001*;* *! Scanning rate 10 kHz*

7. A whole section of the setup file can be commented out, by preceding the section with a line containing the sequence **/*** and ending the section with a line containing the sequence ***/** . This procedure can be used to quickly comment out a section containing a data block which is not used in a particular test, but which may be used in a subsequent test.

8. A group name can be enclosed in square brackets if so desired.

5.2 General Group

Parameters entered and the data that they refer to are listed in Table 5.2. A sample **General Group** is presented and discussed in Section 5.2.1.

Table 5.2 Data contained in the General Group

Parameter Name	**Description of Data**
No. of channels	Number of channels or columns of data stored in the sensor data file. **Please Section 6.1. If the number of channels are defined in the sensor setup file, it will be read from the sensor data file.**
Time Step	Time step, in seconds, for data in sensor data files. This is the inverse of the sampling frequency of the DAS
Time Unit	Time unit used for output. The time is displayed in the first column of the output file. If the Time Unit can be defined as **sec** or **msec**. If the Time Unit is msec, then the time values are converted to milliseconds prior to display.
Initial Time	Value of time of first record in sensor data file. Should be in seconds. Entry of this parameter is optional. If the value is negative, it normally indicates, time prior to the setting of the event trigger.
Start Time	First value when program output should begin. All records from Initial Time to Start time will be skipped in the Output file. Entry of this parameter is optional
End Time	Last value when output should End. All records within the sensor data file which occur after the End Time will be disregarded. Entry of this parameter is optional.
Output Step	Interval between time steps in the program output. Output file will contain data at intervals = Output Time Step * Time Step
Header Lines	Number of header lines in the sensor data file. Default value is 0 (Zero). Header lines are text information placed at the start of the file, such as column titles, test information, etc. If the Header Lines parameter was not entered, then the program will scan the beginning of the file and skip all lines with non-numeric characters. Header lines, however, may contain numeric data as long as they are declared explicitly as a Header Line. **Please see example below in Section 5.2.2.**

NOTE:	If Start Time is defined, then the changes in length of the CRUX or the DGSP will be calculated relative to the length at Start Time.

5.2.1 Example of General Group Data

An example is given below to illustrate how data can be defined in the **General** block. Each entry is followed by a comment.

```
General
No. of Channels = 15;      ! No. of columns of data in sensor data file
Time Step = .0001;         ! Indicates a sampling rate of : 1/.0001 = 10000 Hz
Initial Time = -.20;       ! First sample is 200 milliseconds before event start
Start Time = .0            ! Start of event to be recorded
End Time =   .3            ! End time to be processed by program
Time Unit = msec;          ! Output will be milliseconds (see Time Scale)
Output Step = 5;           ! Output will be recorded at every fifth sample point
Header Lines = 2;          ! Sensor data file has 2 header lines
```

The above would imply that there are 15 channels (or columns) of data stored in the data file. The data was recorded at intervals of .0001 secs or at a sampling rate of 10000 samples/sec. The Time Scale parameter indicates that the output time will be the input time multiplied by 1000, or in milliseconds. The first record represents a time of -.2 sec. This would imply that the actual event started 200 milliseconds after recording began. The program will skip 2000 records (from -.2 to -.0001) and start processing from time value = .0 sec and continue processing to .3 sec. The output will be presented at intervals of 5 x .0001 sec, i.e. .0005 sec or .5 millisecond. Since the Header Lines parameter is entered, the program will expect two header lines in the file before the data columns start.

5.2.2 Header Lines Definition

The following examples should help in understanding how the Header Parameter can be used.

```
Test #1
Sled test of Thor
Column_1   Column_2
(sec)          (mm)
.000           .01
.001           .05
.002           .16
```

Example A

```
Test #2
Kroell Test Thor
.0000
Column_1   Column_2
(sec)          (mm)
.000           .01
.001           .05
.002           .16
```

Example B

In **Example A**, there are four header lines with alphanumeric information, and the column data begins from input line 5. In this case, the value of the parameter **Header Lines** will be 4 as shown below.

`Header Lines = 4;` and the results would be the same.

In **Example B**, there are 5 header lines including line 3 which contains numeric data. In order for this to be correctly interpreted, the parameter **Header Lines** should be defined to be 5 as shown below.

```
Header Lines = 5;
```

5.3 CRUX Group

Data for the CRUX instrumentation in the Thor thorax are arranged according to the four locations as shown below.

1. Upper Right
2. Upper Left
3. Lower Right
4. Lower Left

For each CRUX location, two sub-groups of data are needed. The basic setup data **(Sec. 5.3.1)** sub-group defines the geometric data and the sensor data **(Sec. 5.3.2)** sub-group defines the channel data. Procedure for entering CRUX related data is illustrated in the flow chart shown below.

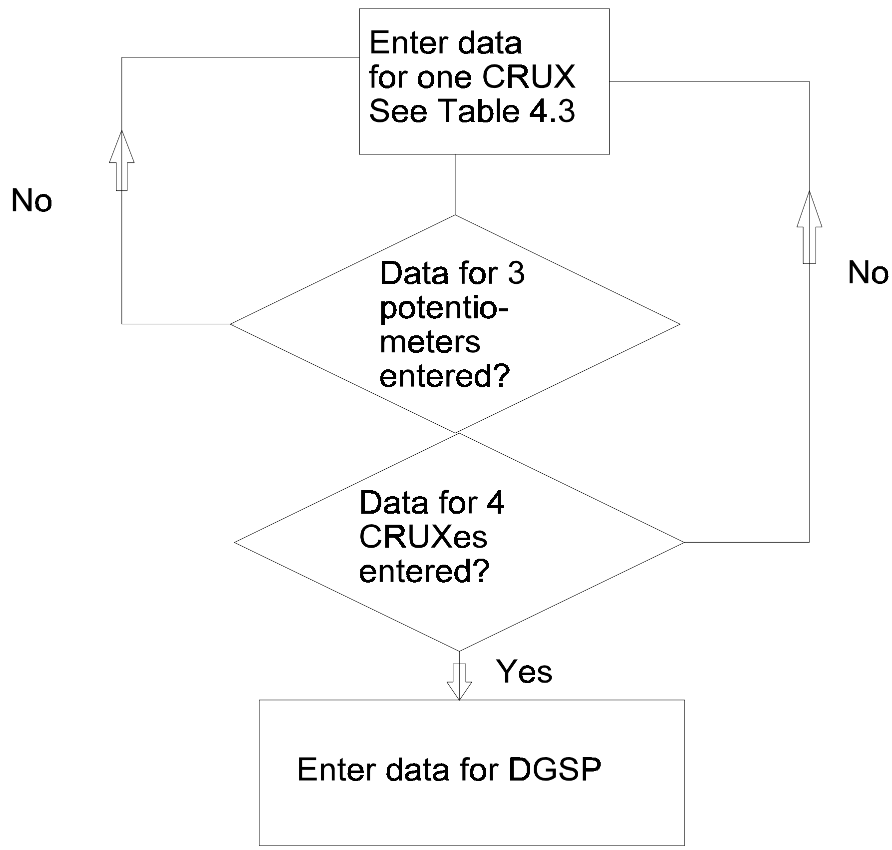

Figure 5.1 Flow chart for entering CRUX related data

> **Note: If data for all three potentiometers associated with a specified CRUX are not provided, then calculations of the deflections will not be made for that CRUX.**

5.3.1 Geometry Subgroup

These parameters normally do not change between tests, for each of the four CRUX units within Thor, and the values in the thorsensor.set file should not be changed. Data in this file and their format is discussed in **Section 8**.

5.3.2 Sensor Data Subgroup

For each CRUX unit, there are three potentiometers which are defined as Base, Mid and Elbow. The principal components of CRUX including the potentiometers are shown in the figure below.

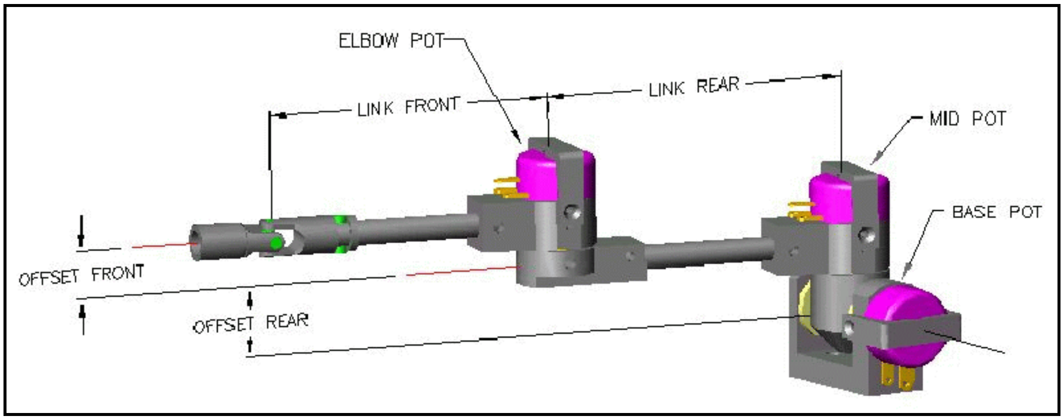

Figure 5.2 Components of a CRUX unit.

Data entered for each potentiometer is listed in Table 5.3 below. The necessary data for each potentiometer is provided through a set of parameters. The typical input for a Crux location is:

Crux_name

Potentiometer_Location

Column = *value*; Filter = *value*; Polarity = *value*; Initial Value = *value*;

These parameters are described in the table below.

Table 5.3 CRUX data definition

Parameter	**Description**
Crux_name	Type in name of the CRUX: Can have the following names: Upper Right Upper Left Lower right Lower left
Potentiometer_Location	Type in location of potentiometer on the CRUX: Can have the following names: Base Mid Elbow
Column	Column number in the sensor data file containing the data for the specific potentiometer

Parameter	Description
Filter	Enter the frequency of the filter to be used by the program. **Note :** If a "0 (Zero)" is entered, the input data will not be filtered.
Initial Value	Angle measured by the potentiometer at the start of test. Necessary, only when the CRUX potentiometer is zeroed through the data acquistion system.
Polarity	Polarity of the signal. The possible values are +1 and -1. If the sensor data is not collected according to the J1733 convention, then its sign can be changed using this field.

Note 1: Only the **Column** parameter is required. If the other parameters are not entered, then, it will be assumed:
Filter = 0;
Initial Value = 0;
Polarity = 1;

Note 2:. If a non-zero value for Filter is given, then a second order Butterworth filter will be computed, with zero phase shift and a falloff of -3dB at a frequency of Filter/1.25. To provide the filter frequency corresponding to a channel filter class (CFC), the CFC value should be multiplied by 1.65 and the result entered as the filter frequency (e.g. CFC = 180. corresponds approximately to Filter = 300.)

5.3.3 Example Sensor Setup File for CRUX

The file will start with definition of all data required under the group GENERAL. The definition of data pertaining to the CRUX system will be entered next as shown in the sample below.

```
[CRUX]
        Upper Right
                Base
                        Column = 2
                        Filter = 300.
                        Initial Value = 168.9
                        Polarity = 1
                Mid
                        Column = 3
                        Filter = 300.
                        Initial Value = 109.4
                        Polarity = 1
                Elbow
                        Column = 4
                        Filter = 300.
                        Initial Value = 180.6
                        Polarity = 1
```

Upper Left
Base
Column = 5
Filter = 300.
Initial Value = 143.4
Polarity = -1
Mid
Column = 6
Filter = 300.
Initial Value = 210.6
Polarity = 1
Elbow
Column = 7
Filter = 300.
Initial Value = 143.0
Polarity = 1

Lower Right
Base
Column = 8
Filter = 300.
Initial Value = 170.4
Polarity = -1
Mid
Column = 9
Filter = 300.
Initial Value = 183.2
Polarity = 1
Elbow
Column =10
Filter = 300.
Initial Value = 147.9
Polarity = 1

Lower Left
Base
Column = 11
Filter = 300.
Initial Value = 146.4
Polarity = 1
Mid
Column = 12
Filter = 300.
Initial Value = 140.1
Polarity = 1
Elbow
Column = 13
Filter = 300.
Initial Value = 175.1
Polarity = 1

The parameters for a specific potentiometer can be given in any order and more than one could be placed in one line (with the use semicolons separating the parameters). E.g. the following input are all equivalent.

Input Case 1:

Base
    Column = 2
    Filter = 300.
    Initial Value = 168.9
    Polarity = 1

Input Case 2:

Base
    Column = 2; Filter = 300.;
    Initial Value = 168.9; Polarity = 1;

Input Case 3:

Base
    Column = 2; Filter = 300; Initial Value = 168.9; Polarity = 1

5.3.4 Setup with Individual Data Files

It is possible to insert the names of the data files within the setup file. In this case, the program will not prompt the user for the input data file name. It will automatically access the files indicated in the setup file. As an example, the following shows how the setup file will look for the Upper Right CRUX unit.

```
Upper Right
    Base
        File = d:\test\sled10\test10.011
        Column = 1
        Filter frequency = 300.
        Initial value = 168.9
        Polarity = 1
    Mid
        File = d:\test\sled10\test10.012
        Column = 1
        Filter frequency = 300.
        Initial value = 109.4
        Polarity = 1
    Elbow
        File = d:\test\sled10\test10.013
        Column = 1
        Filter frequency = 300.
        Initial Value = 180.6
        Polarity = 1
```

In the above, the parameter "**File**" indicates the location of the file for the corresponding potentiometer data. Also, in this example, the parameter **"Column"** indicates that the data for the potentiometer will found in column 1 of the file.

The ISO format requires that data from each sensor be stored in a separate file with only one column and a certain prescribed number of header lines. Thus, when data is stored in ISO format, the setup file would have to be defined as shown in the above example.

5.4 DGSP Group

Data have to be provided for the two DGSPs listed below:

1. Right
2. Left

For each DGSP, data has to be provided for the following components of the DGSP. Data relating to each component is preceded by a keyword.

1. String potentiometer
2. Rotary potentiometer in the X-Y plane (θ **or Theta rotation)**
3. Rotary potentiometer in the Z-X plane (**ψ or Psi rotation**)

Two sub-groups of data are needed for each string potentiometer and rotary potentiometers of each DGSP. The basic setup **(Sec. 5.4.1)** sub-group defines the geometric data and the sensor data **(Sec.5.4.2)** sub-group defines the channel data. Procedure for entering DGSP related data is illustrated in the flow chart shown below.

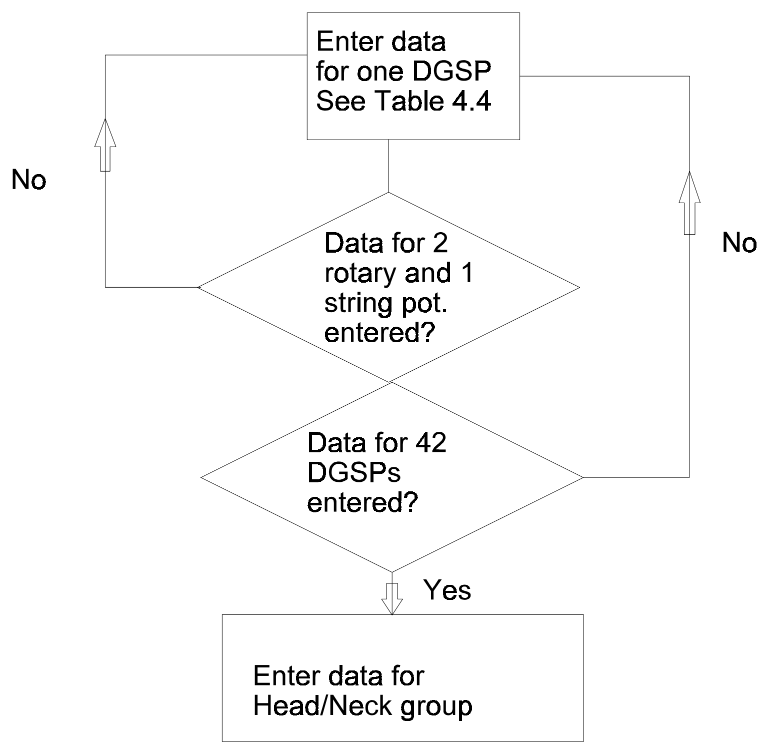

Figure 4.2 Data entry for DGSPs

Note : If data for all three potentiometers associated with a specified DGSP is not provided, then calculations of the deflections will not be made for that DGSP.

5.4.1 Geometry Subgroup

These parameters are fixed for each of the DGSP units within Thor, and the values in the thorsensor.set file should not be changed. Data in this file and their format is discussed in **Section 8.**

5.4.2 Sensor Data Subgroup

For each DGSP unit, there are three sensors which are defined as Stringpot, Theta and Psi. Data entered for each potentiometer is listed in Table 5.4 below. The necessary data for each potentiometer is provided through a set of parameters. The typical input for a DGSP location is:

DGSP_name

Sensor_Name

Column = *value*; Filter = *value*; Polarity = *value*; Initial Value = *value*;

These parameters are described in the table below.

Table 5.4 Data definition for DGSP

Parameter	**Description**
DGSP_name	Type in name of the DGSP. Can have the following names: Right Left
Sensor_name	Type in name of sensor. Can have the following names: Stringpot Theta Psi
Column	Column number in the sensor data file containing the data for the specific DGSP sensor.
Filter frequency	Enter the frequency of the filter to be used by the program. **Note :** If a "0 (Zero)" is entered, the input data will not be filtered.

Parameter	Description
Initial value	Engineering value of the sensor at the start of test. Necessary when a DGSP potentiometer is zeroed through the data acquisition system.
Polarity	Polarity of the signal. If the sensor data is not collected according to the J1733 convention, then its sign can be changed using this field.

Note 1: Only the **Column** parameter is required. If the other parameters are not entered, then, it will be assumed:
Filter = 0;
Initial Value = 0;

Note 2: If a non-zero value for Filter is given, then a second order Butterworth filter will be computed, with zero phase shift and a falloff of -3dB at a frequency of Filter/1.25. To provide the filter frequency corresponding to a channel filter class (CFC), the CFC value should be multiplied by 1.65 and the result entered as the filter frequency (e.g. CFC = 180. corresponds approximately to Filter = 300.)

An example of data entered in the data sub-group is illustrated below.

5.4.3 Example Data File for DGSP

```
[DGSP]
        Right
                Stringpot
                        Column  = 1
                        Filter = 300.
                        Initial value = 17.
                        Polarity = -1
                Theta       ! (X - Y rotation)
                        Column = 2
                        Filter = 300.
                        Initial value = 160.
                        Polarity = -1
                Psi       ! (Z - X rotation)
                        Column = 3
                        Filter = 300.
                        Initial value = 161.
                        Polarity = 1

        Left
                Stringpot
                      Column  = 4
                        Filter = 300.
                        Initial value = 14.
```

```
            Polarity = -1

        Theta
            Column  = 5
            Filter = 300.
            Initial value = 155.
            Polarity = -1
        Psi
            Column  = 6
            Filter = 300.
            Initial value  = 177.
            Polarity = -1
```

The parameters for a specific potentiometer can be given in any order and more than one could be placed in one line (with the use semicolons separating the parameters). E.g. the following input are all equivalent.

Input Case 1:

```
    Stringpot
        Column  = 1
        Filter = 300.
        Initial value = 17.
        Polarity = -1
```

Input Case 2:

```
    Stringpot
        Column = 1; Filter = 300.;
        Initial Value = 17.; Polarity = -1;
```

Input Case 3:

```
    Stringpot
        Column = 1; Filter = 300; Initial Value = 17.; Polarity = -1
```

This above example describes the data needed for DGSP calculations. In this example, it is expected that data for the two DGSP units will reside in a single data file and the different potentiometer data will be located in columns specified by the Column values.

5.4.4 Setup with Individual Data Files

The setup file for the DGSP can also contain the names of the files which contain data for a single channel (as for ISO format). The example data below shows how file names can be defined for the Right DGSP.

```
    Right
        Stringpot
            File = d:\test\sled10\test10.021
           Column  = 1
            Filter = 300.
```

```
            Initial value  = 17.
            Polarity = -1
Theta          ! (X - Y rotation)
            File = d:\test\sled10\test10.022
            Column  = 1
            Filter = 300.
            Initial value  = 160.
            Polairty = -1
Psi          ! (Z - X rotation)
            File = d:\test\sled10\test10.023
            Column  = 1
            Filter = 300.
            Initial value = 161.
            Polarity = 1
```

5.5 Neck Data

This section deals with data required to calculate the force and moments acting on the head due to the neck at the Occipital Condyle pin (O.C.). The following sub-groups are defined for the Neck Data block.

Table 5.5 Data definition for Neck data

Sub-Group Name	**Data entered**
Neck Force	Block for defining upper neck load cell data. The block is divided into the following identifiers Fx, Fy, Fz, Mx, My, Mz
Neck rear spring	Block for defining rear spring force
Neck front spring	Block for defining front spring force
OC Potentiometer	Block for defining OC potentiometer data

The parameters that may need to be defined for these sub-groups are the same as those described for the Crux and DGSP and are shown in the table below.

Table 5.6 Data definition for Neck

Parameter	**Description**
Column	Column number in the sensor data file containing the data for the specific DGSP sensor.
Filter frequency	Enter the frequency of the filter to be used by the program. **Note :** If a “0 (Zero)” is entered, the input data will not be filtered.

Parameter	Description
Initial value	Engineering value of the sensor at the start of test. Necessary when the rotary potentiometer sensor is zeroed through the data acquisition system. Load cells are normally zeroed out and do not need any initial values.
Polarity	Polarity of the signal. If the sensor data is not collected according to the J1733 convention, then its sign can be changed using this field.

Note 1: Only the **Column** parameter is required. If the other parameters are not entered, then, it will be assumed:
Filter = 0;
Initial Value = 0;

Note 2: If a non-zero value for Filter is given, then a second order Butterworth filter will be computed, with zero phase shift and a falloff of -3dB at a frequency of Filter/1.25. To provide the filter frequency corresponding to a channel filter class (CFC), the CFC value should be multiplied by 1.65 and the result entered as the filter frequency (e.g. CFC = 180. corresponds approximately to Filter = 300.)

5.5.1 Example Input for Neck Data

An example setup file for the Neck group data is shown below.

```
[NECK]
        Neck Force
                Fx
                        Column  = 1
                        Filter = 600
                        Polarity = 1
                Fy
                        Column = 2
                        Filter = 600
                        Polarity = 1
                Fz
                        Column = 3
                        Filter = 600
                        Polarity = 1
                Mx
                        Column = 4
                        Filter = 600
                        Polarity = 1
                My
                        Column = 5
                        Filter = 600
                        Polarity = 1
```

```
        Mz
                Column = 6
                Filter = 600
                Polarity = 1


    Rear Spring
        Channel = 7
        Filter = 600
        Polarity = 1

    Front Spring
        Channel = 8
        Filter = 600
        Polarity = 1

    Rotation
        Channel = 9
        Filter = 600
        Polarity = 1
```

The parameters for a specific potentiometer can be given in any order and more than one could be placed in one line (with the use semicolons separating the parameters). E.g. the following input are all equivalent.

Input Case 1:

```
    Mx
        Column  = 1
        Filter = 600.
        Polarity = 1
```

Input Case 2:

```
    Mx
        Column = 1; Filter = 600.;
        Polarity = 1;
```

Input Case 3:

```
    Mx
        Column = 1; Filter = 600; Polarity = 1
```

5.5.2 Setup with Individual Data Files

The setup file for the Neck data can also contain the names of the files which contain data for a single channel (as for ISO format). The example data below shows how file names can be defined for the Neck Force.

```
    Neck Force
        Fx
            File = d:\test\sled10\test10.011
```

```
                Column  = 1
                Filter = 600
                Polarity = 1

        Fy
                File = d:\test\sled10\test10.012
                Column = 2
                Filter = 600
                Polarity = 1
        Fz
                File = d:\test\sled10\test10.013
                Column = 3
                Filter = 600
                Polarity = 1
        Mx
                File = d:\test\sled10\test10.014
                Column = 4
                Filter = 600
                Polarity = 1
        My
                File = d:\test\sled10\test10.015
                Column = 5
                Filter = 600
                Polarity = 1
        Mz
                File = d:\test\sled10\test10.016
                Column = 6
                Filter = 600
                Polarity = 1
```

5.6 Ankle Data

This section deals with data required to calculate the moments acting at the ankle joint based on the loads measured at the lower tibia load tibia cell, and the tibia accelerometers. The following subgroups are defined for the Ankle Data block. The Lower Tibia subgroup is further divided into two sub-subgroups

Table 5.7 Data definition for Ankle data

Subgroup Name	Sub-subgroup	Data entered
Lower Tibia	Load Cell	Block for defining lower tibia load cell data. Includes the following identifiers: Fx, Fy, Fz, Mx, My
	Accelerometer	Block for defining lower tibia accelerometer data. Includes the following identifiers: Ax, Ay
Ankle Pot		Block for defining ankle potentiometer data
Achilles		Block for defining Achilles load data

The parameters that may need to be defined for these sub-groups are the same as those described for the Crux and DGSP and are shown in the table below.

Table 5.8 Data definition for Ankle

Parameter	**Description**
Column	Column number in the sensor data file containing the data for the specific DGSP sensor.
Filter frequency	Enter the frequency of the filter to be used by the program. **Note :** If a “0 (Zero)” is entered, the input data will not be filtered.
Initial value	Engineering value of the rotary potentiometers at the start of test. Necessary when the sensor is zeroed through the data acquisition system. Load cells and accelerometers are normally zeroed and do not require initial values.
Polarity	Polarity of the signal. If the sensor data is not collected according to the J1733 convention, then its sign can be changed using this field.

Note 1: Only the **Column** parameter is required. If the other parameters are not entered, then, it will be assumed:
Filter = 0;
Initial Value = 0;

Note 2: If a non-zero value for Filter is given, then a second order Butterworth filter will be computed, with zero phase shift and a falloff of -3dB at a frequency of Filter/1.25. To provide the filter frequency corresponding to a channel filter class (CFC), the CFC value should be multiplied by 1.65 and the result entered as the filter frequency (e.g. CFC = 180. corresponds approximately to Filter = 300.)

5.6.1 Example Input for Ankle Data

An example setup file for the Ankle group data is shown below.

```
[Ankle]

  [Lower Tibia]

    Load Cell
      Fx
        Column = 1;
        Filter = 1000;
        Polarity = 1;
```

```
    Fy
      Channel = 2;
      Filter = 1000;
      Polarity = 1;
    Fz
      Column = 3;
      Filter = 1000;
      Polarity = 1;
    Mx
      Column = 4;
      Filter = 1000;
      Polarity = 1;
    My
      Column = 5;
      Filter = 1000;
      Polarity = 1;

  Accelerometer

     Ax
      Column = 6;
      Filter = 1000;
      Polarity = 1;

    Ay
      Column = 7;
      Filter = 1000;
      Polarity = 1;


 [Ankle Pot]

   X Pot
        Column = 7;
        Filter = 300;
        Polarity = -1;

   Y POT
        Column = 8;
        Filter = 300;
        Polarity = 1;

   Z POT
        Column = 9;
        Filter = 300;
        Polarity = 1;

 [Achilles]
        Column = 10;
        Filter = 1000;
        Polarity = 1;
```

The parameters for a specific potentiometer can be given in any order and more than one could be placed in one line (with the use semicolons separating the parameters). E.g. the following input are all equivalent.

Input Case 1:

```
Fx
        Column  = 1
        Filter = 1000.
        Polarity = 1
```

Input Case 2:

```
Fx
        Column = 1; Filter = 1000.;
        Polarity = 1;
```

Input Case 3:

```
Fx
        Column = 1; Filter = 1000; Polarity = 1
```

5.6.2 Setup with Individual Data Files

The setup file for the Ankle data can also contain the names of the files which contain data for a single channel (as for ISO format). The example data below shows how file names can be defined for the Lower Tibia Load Cell.

```
Load Cell
  Fx

    File = d:\test\sled10\test10.020
    Column = 1;
    Filter = 1000;
    Polarity = 1;
  Fy
    File = d:\test\sled10\test10.021
    Channel = 2;
    Filter = 1000;
    Polarity = 1;
  Fz
    File = d:\test\sled10\test10.022
    Column = 3;
    Filter = 1000;
    Polarity = 1;
  Mx
    File = d:\test\sled10\test10.023
    Column = 4;
    Filter = 1000;
    Polarity = 1;
  My
    File = d:\test\sled10\test10.024
    Column = 5;
    Filter = 1000;
    Polarity = 1;
```

6. Sensor Data Format

The program requires that all data from sensors be in appropriate engineering units. Data should be in columns separated by blanks or comma. Data from all the sensors can be in one file. The program can read sensor data from a maximum of 150 columns (channels) of column width 12 with blank or comma as separators. If there are more than 150 columns (channels) of data, users are requested to split the sensor data into two or more files as appropriate.

Sensor data files can also be in the ISO format. Data from each sensor can be stored in one file. Header lines are allowed as long as their number is declared as a part of the section named **GENERAL** in the SETUP file.

7. Program Output

The program uses the data from the two setup files (**thorsensor.set** and the user setup file) and the SENSOR DATA files to produce the following output:

1. X , Y, and Z deflections of each CRUX and the change in length (D) between the two end points of each CRUX.

2. X, Y and Z deflections of each DGSP.

3. Total X, Y and Z force and moments acting on the head due to the neck, acting through a plane separating the head and neck at the O.C. joint. Also the forces and moments acting on the head due to the neck, only at the O.C (in the Z-X plane).

4. The Mx and My moments acting at the ankle and subtalar joints, and the rotation angles measured by the corresponding potentiometers, and the total My moment acting through a section cutting across the ankle joint.

Output from each sensor system will be discussed below.

7.1 Output from CRUX

The ASCII output file will list time in the first column. In addition, there will be 4 columns for each CRUX. The first 3 columns represent chest compression in the X, Y and Z directions. Data in the fourth column represent a change in length between the two end points of the linkage (D). Output data from the CRUX are presented in the following order.

1. Upper Right CRUX : X, Y and Z deflections, respectively, in the first 3 columns and change in length (UR-D) in the 4th column.

2. Upper Left CRUX : X, Y and Z deflections, respectively, in the first 3 columns and

change in length (UL-D) in the 4th column

3. Lower Right CRUX : X, Y and Z deflections, respectively, in the first 3 columns and change in length (LR-D) in the 4th column

4. Lower Left CRUX : X, Y and Z deflections, respectively, in the first 3 columns and change in length (LL-D) in the 4th column

7.2 Output from DGSP

The ASCII output file will list time in the first column. In addition, there will be 3 columns of output for each DGSP. The data in these columns represent the X, Y and Z displacement of the DGSP. Output data from the DGSP are presented in the following order:

1. Right DGSP X displacement
2. Right DGSP Y displacement
3. Right DGSP Z displacement
4. Left DGSP X displacement
5. Left DGSP Y displacement
6. Left DGSP Z displacement

7.3 Output from the Neck

The ASCII output file will have 10 columns. The first column will tabulate time in increasing values, and the next 9 columns will list the following output variables :

1. X Force (on head acting through total neck section)
2. Y Force (on head acting through total neck section)
3. Z Force (on head acting through total neck section)
4. X Moment (on head acting through total neck section)
5. Y Moment (on head acting through total neck section)
6. Z Moment (on head acting through total neck section)
7. X Force (on head acting through O.C. joint only)
8. Z Force (on head acting through O.C. joint only)
9. Y Moment (on head acting through O.C. joint only)

Loads and moments are in the head coordinate system. If the OC potentiometer data is missing, the program will assume that the relative angle between the head and the top of the neck is zero.

7.4 Output from the Ankle

The ASCII output file will have 9 columns. The first column will tabulate time in increasing values, and the next 8 columns will list the following output variables:

1. Ankle X Force
2. Ankle Y Force
3. Ankle Z Force
4. Ankle Mx Moment
5. Ankle My Moment
6. Rotation about ankle X-axis (subtalar joint)
7. Rotation about ankle Y-axis (ankle joint)
8. Ankle Section My Moment (if Achilles load measured)

The forces and moments are in the coordinate system of the tibia segment below the lower tibia load cell (and below the Z-rotation joint). Only the sensors that are actually read in are displayed in the table. If the lower tibia load cell Fx is missing, the ankle My moment is not calculated. If the lower tibia load cell Fy is missing, the ankle Mx is not calculated.

8. Structure and Format of Thorsensorset File

The **thorsensor.set** file will be supplied by the manufacturer of the dummy or the entity that integrates sensors into the dummy. It will contain data about the geometry and calibration factors of the CRUX, DGSP, the sensors used for measuring loads on the head at the O.C., and the sensors used for measuring loads at the ankle joint.

Data in the **thorsensor.set** file should not be changed unless any of the sensors used in the calculations described for the CRUX, the DGSP, neck, and ankle are replaced. In case any of the items mentioned are replaced, appropriate information about the replaced parts should be entered in the **thorsensor.set** file. Information to be entered should ideally be obtained from the manufacturer or the instrumentation integrator.

Data pertaining to each instrumentation group are described in the next few sections.

8.1 CRUX Group

Geometry of each of the CRUX units, the calibration constant of each of the potentiometers, and the Setup angle are defined for each potentiometer in each CRUX. Please refer to Appendix A for definition of the terms Link Rear, Link Front, Offset Rear, Offset Front and Setup angle which are used in the data set.

A sample SETUP data set for the CRUX units is given below.

```
CRUX
        Upper Right
                Link Rear = 79.25;  Link Front = 67.75;
                Offset Rear = 18.16;  Offset Front = 9.91
```

```
        Base
                Calibration = 1.; Setup = 158.;
        Mid
                Calibration = 1.; Setup = 68.8
        Elbow
                Calibration = 1.; Setup = 256.

    Upper Left
        Link Rear = 79.25;  Link Front = 67.75
        Offset Rear = 18.16;  Offset Front = 9.91;

        Base
                Calibration = -1.;  Setup = 154.

        Mid
                Calibration = 1.;  Setup = 251.
        Elbow
                Calibration = 1.;  Setup = 71.4

    Lower Right
        Link Rear = 85.60;  Link Front = 73.10
        Offset Rear = 18.16;  Offset Front = 9.91

        Base
                Calibration = -1.;  Setup = 158.
        Mid
                Calibration = 1.;  Setup = 253.
        Elbow
                Calibration = 1.;  Setup = 64.6

    Lower Left
        Link Rear = 85.60;  Link Front = 73.10
        Offset Rear = 18.16;  Offset Front = 9.91

        Base
                Calibration = 1.;  Setup = 159.
        Mid
                Calibration = 1.;  Setup = 84.2
        Elbow
                Calibration = 1.;  Setup = 251.
```

8.2 DGSP Group

The calibration constant and the setup value for each of the potentiometers in the DGSP are defined in the file. Appendix B describes the computation used for obtaining the abdomen deflections using the DGSPs. A sample file is shown below.

```
DGSP
    Right
        Stringpot
                Calibration = -1.0;  Setup = 186.
        Theta
                Calibration = -1.0;  Setup = 158.
```

Psi

Calibration = 1.0; Setup = 163.

Left

Stringpot

Calibration = -1.0; Setup = 182.

Theta

Calibration = -1.0; Setup = 155.

Psi

Calibration = -1.0; Setup = 174.

8.3 Neck Group

Several subgroups are defined for the overall Neck group. The subgroups are:

Neck Force
Rear Spring
Front Spring
Rotation

Each of the above subgroups have additional parameters or other subgroups defined, which are described in the following subsections. A description of how the forces and moments are computed at the O.C. from the load cell measurements is given in Appendix C.

8.3.1 Neck Force Subgroup

For calculating the load acting on the head due to the neck, the X, Y, and Z force and moment components of the upper neck load cell have to be defined. In addition, for carrying out moment calculations, the location of the center of the neck load cell relative to the O.C. has to be defined along with the X, Y, and Z moment components of the load cell.

Thus the following subgroups are defined for this category:

Location — (X, Y, and Z coordinates of the center of upper neck load cell relative to O.C. These measurements are in meters. These values are normally supplied and will not change for the current dummy dimensions.)

FX |
FY | (3 components required for calculating external force)
FZ |

MX |
MY | (3 components required for moment calculations)

MZ |

The channel data corresponding to the force and moment components are defined as for the other instrumentation described previously (Sections 8.1 and 8.2).

8.3.2 Rear Spring Subgroup

For a correct computation of any external force acting on the head, the force acting along the cable connected through the rear spring in the head has to be determined. The following subgroups are defined (all position values in meters):

Top	(location of the top of the active segment of the rear cable on the head, relative to the O.C. The X, Y, Z coordinates of the top of the cable is defined.)
Bottom	(location of the bottom of the active segment of the rear cable on the neck, relative to the O.C. The X, Y, Z coordinates of the bottom of the cable is defined.)

The above data are usually supplied and would not change. Channel definition for the load cell at the rear spring is according to the format described previously.

8.3.3 Front Spring subgroup

For a correct computation of any external force acting on the head, the force acting along the cable connected through the front spring in the head has to be determined. The following subgroups are defined (all position values in meters):

Top	(location of the top of the active segment of the front cable on the head, relative to the O.C. The X, Y, Z coordinates of the top of the cable is defined.)
Bottom	(location of the bottom of the active segment of the front cable on the neck, relative to the O.C. The X, Y, Z coordinates of the bottom of the cable is defined.)

The above data are usually supplied and would not change. Channel definition for the load cell at the front spring is according to the format described previously.

8.3.4 Rotation Subgroup

This subgroup simply defines the channel data for the rotary potentiometer placed at the occipital condyle to measure the rotation of the head relative to the top of the neck.

Data for the force measured at the neck load cell, the forces measured by the load cells at the rear and front spring and the angle measured by the rotary potentiometer are all required for correct computation of the total force acting on the head transmitted through the neck.

8.3.5 Example Setup Data for Neck Group

```
[Neck]

  Neck Force
      Location
         X = 0.;  Y = 0.;  Z = .0254;            !Location of mid-pt of load cell
      FX
         Calibration = 1; Setup = 0.;
      FY
         Calibration = 1; Setup = 0.;
      FZ
         Calibration = 1; Setup = 0.;
      MX
         Calibration = 1; Setup = 0.;
      MY
         Calibration = 1; Setup = 0.;
      MZ
         Calibration = 1; Setup = 0.;

  Rear Spring
     Top
       X = -.060; Y = 0.; Z = .0086;
     Bottom
       X = -.0396; Y = 0.; Z = .0472;

     Calibration = 1.; Setup = 0.;

  Front Spring
     Top
       X = .0381; Y = 0.; Z = -.0086;
     Bottom
       X = .0381; Y = 0.; Z = .0206;

     Calibration = 1.; Setup = 0.;

  Rotation
     Calibration = 1.; Setup = 0.;
```

8.4 Ankle Group

Several subgroups are defined for the overall Ankle group. The subgroups are:

Lower Tibia

Ankle Pot
Achilles

Each of the above subgroups have additional parameters or other subgroups defined, which are described below. The computational procedure used for obtaining the moments at the ankle are given in Appendix D.

8.4.1 Lower Tibia Subgroup

For calculating the load acting at the ankle on the lower tibia, the X, Y, and Z force and moment components of the lower tibia load cell and the tibia accelerometer will have to be defined. In addition, for carrying out moment calculations, the location of the center of the neck load cell relative to the ankle and subtalar joints have to be defined.

The **mass** parameter is defined for the group, which provides the mass of the segment of the lower tibia included between the center of the lower tibia load cell and the ankle.

The Lower Tibia subgroup is further divided into two sub-subgroups:

Load Cell
Accelerometer

The data for these sub-subgroups are described below.

Lower Tibia - Load Cell subgroup

The X, Y, and Z coordinates of the center of lower tibia load cell relative to the ankle are given. These measurements are in meters. These values are normally supplied and will not change for the current dummy dimensions.

The following identifiers are also defined

FX |
FY | (3 components required for calculating ankle loads)
FZ |

MX |
MY | (2 components required for moment calculations)

The channel data corresponding to the force and moment components are defined as for the other instrumentation described previously (Sections 8.1 and 8.2).

Lower Tibia - Accelerometer subgroup

The X, Y, and Z coordinates of the average position of the accelerometer attached to the lower tibia are given. These measurements are in meters. These values are normally supplied and will not change for the current dummy dimensions.

The following identifiers are also defined

AX |
AY | (2 components required for calculating ankle loads)

8.4.2 Ankle Pot Subgroup

This subgroup provides information on the location of the ankle rotary potentiometers and the calibration and setup values. The data is arranged in the following sub-subgroups:

X Pot

The location of the pot (Z coordinate only) relative to the ankle joint is given, followed by the data for the calibration and initial setup angle. The setup angle is the reading of the pot when the foot is at right angles to the tibia.

Y Pot

The calibration and initial setup angle is provided. The setup angle is the reading of the pot when the foot is at right angles to the tibia.

Z Pot

The location of the pot (Z coordinate only) relative to the ankle joint is given, followed by the data for the calibration and initial setup angle. The setup angle is the reading of the pot when the foot is at right angles to the tibia.

8.4.3 Achilles Subgroup

For the computation of the sectional moment through the cross-section at the ankle, the force generated in the Achilles cable has to be included. The following subgroups are defined (all position values in meters):

Top (location of the top of the active segment of the Achilles cable - attached to the tibia. The X, Y, Z coordinates of the top of the cable, relative the ankle joint is defined.)

Bottom (location of the bottom of the active segment of the Achilles cable attached to the foot. The X, Y, Z coordinates of the bottom of the cable, relative to the ankle joint is defined.)

The above data are usually supplied and would not change. Channel definition for the load cell at the Achilles is according to the format described previously.

NOTE:	**If the Achilles load cell is not present, and is not included in the user sensor setup file, then the ankle section moment will not be calculated.**

8.4.4 Example Setup Data for Ankle Group

```
[Ankle]

  [Lower Tibia]

    Mass = .720;

    Load Cell
       X = 0.;  Y = 0.;  Z = -.0907;

      FX
        Calibration = 1.; Setup = 0;
      FY
        Calibration = 1.; Setup = 0;
      FZ
        Calibration = 1.; Setup = 0.;
      MX
        Calibration = 1.; Setup = 0;
      MY
        Calibration = 1.; Setup = 0.;


    Accelerometer
       X = 0.;  Y = 0.;  Z = -.0454;

      AX
        Calibration = 1.; Setup = 0;
      AY
        Calibration = 1.; Setup = 0;


  [Ankle Pot]

    X Pot
       Z = .0150;

       Calibration = -1.; Setup = 149.5;

    Y Pot
       Calibration = 1.; Setup = 157.3;

    Z Pot
       Z = -.0699;

       Calibration = 1.; Setup = 143.5;
```

```
[Achilles]

  Top
     X = -.0411;  Y = .0;  Z = -.0607;
  Bottom
     X = -.0396;  Y = .0;  Z =  .0201;

  Calibration = 1.; Setup = 0;
```

Appendix A: Deflection Calculations from CRUX Angle Measurements

Figure A.1 below shows the position of the upper right CRUX unit when it is in its standard position and when it is bent at an arbitrary angle. calibration and with all the angles set to their zero positions. The configuration labeled **A** is the standard position, which defines the standard coordinate system of the CRUX unit. In this configuration, the arms of the CRUX are aligned and pointed straight with respect to the base of the unit. **[One should note that the potentiometers themselves may not read zero values when the CRUX is in this orientation.]**

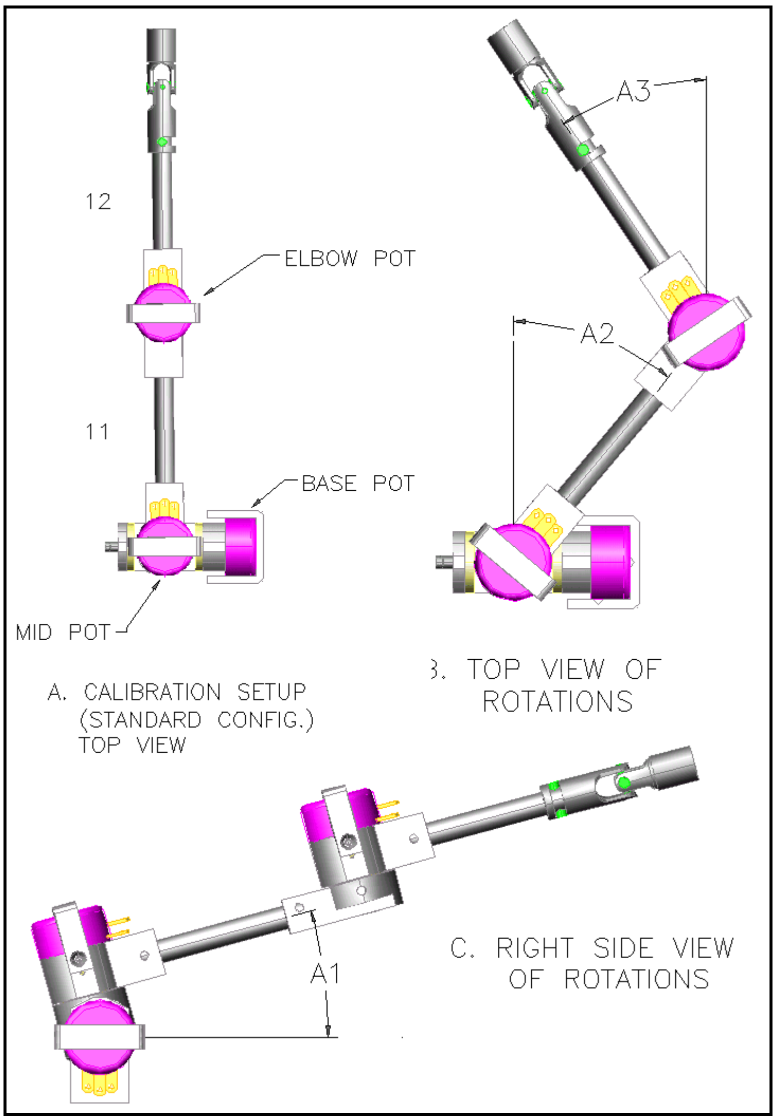

Figure A.1 Upper right CRUX in standard and bent configurations.

All angle changes will be measured with respect to this orientation of the CRUX. Configurations labeled **B** and **C** show the change in angles of each of the pots when the CRUX is oriented in an arbitrary position. The base pot angle, **a1**, measures the inferior-superior angle and is considered positive if the rotation is from the inferior to the superior direction. The mid and elbow pot rotations, **a2** and **a3**, are considered positive if they are clockwise seen from above.

The right-handed coordinate system treats the X-axis in the posterior-anterior direction, the Y-axis in the left-right direction, and the Z-axis in the superior-inferior direction. The origin of the coordinate system is taken to be at the intersection of the plane passing vertically through both the Mid and Elbow pots as seen in position **A** and a straight line passing through the axis of the Base pot.

Voltages are measured when the CRUX unit is in the configuration given in configuration **A**. This then provides the voltages corresponding to the **'zero'** positions of all the pots. The voltage change in each pot relative to this **'zero'** position then gives the corresponding rotation relative to the same **'zero'** position and can be used to find the position of the end of the front arm relative to a fixed point on the axis of the base pot.

The fixed length of the rear arm between the centers of the mid and elbow pots is $\mathbf{l_1}$ and the fixed length between the center of the elbow pot and the end of the front arm is $\mathbf{l_2}$. The vertical offset of the center line of the rear arm from the origin is $\mathbf{l_a}$ and the vertical offset of the center line of the front arm relative to the rear arm is $\mathbf{l_b}$.

A.1 Equations for calculating CRUX deflection from pot rotations

We denote the rotations of the base, mid and elbow pots by $\mathbf{a_1}$, $\mathbf{a_2}$, $\mathbf{a_3}$ respectively. We will calculate the position of the end of the rear arm relative to the origin of the CRUX system. The CRUX may be thought of as consisting of three rigid subsystems. The first one, consists of a coordinate system attached to the base pot at the origin of the CRUX and undergoing rotation a_1. The second subsystem consists of the mid pot and the rear arm and undergoing rotation a_2, and the third subsystem consists of the elbow pot and the front arm undergoing rotation a_3.

The location of the end point of the front arm is given with respect to the origin by the relation:

$$\mathbf{x} = \mathbf{R_1}\,(\mathbf{la} + \mathbf{R_2}\,(\mathbf{l_1} + \mathbf{l_b} + \mathbf{R_3 l_2}\,)\,) \qquad (1)$$

where: $\mathbf{R_1}, \mathbf{R_2}, \mathbf{R_3}$ = rotation matrices associated with the rotations a_1, a_2, a_3
$\mathbf{l_1}$ = vector along length of rear arm (in local **x** direction)
$\mathbf{l_2}$ = vector along length of front arm (in local **x** direction)
$\mathbf{l_a}$ = vector along rear offset (in local **-z** direction)
$\mathbf{l_b}$ = vector along front offset (in local **-z** direction)

The rotation matrices $\mathbf{R_1}, \mathbf{R_2}, \mathbf{R_3}$ are given by:

$$R_1 = \begin{bmatrix} \cos a_1 & 0 & \sin a_1 \\ 0 & 1 & 0 \\ -\sin a_1 & 0 & \cos a_1 \end{bmatrix} \tag{2}$$

$$R_2 = \begin{bmatrix} \cos a_2 & -\sin a_2 & 0 \\ \sin a_2 & \cos a_2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} \cos a_3 & -\sin a_3 & 0 \\ \sin a_3 & \cos a_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

If $\mathbf{x_0}$ is the initial deflection then the change in deflection is given by:

$$\Delta\, \mathbf{x} = \mathbf{x} - \mathbf{x_0}$$

The above equation provides the Δ x, Δ y, and Δ z that are produced by the software program. The last component is defined by:

$$\Delta\, l = |\mathbf{x}| - |\mathbf{x_0}|$$

and represents the change in length between the origin and the end point of the front arm and would correspond to the change in length of an imaginary tube that connects the two points.

As described in the instruction manual for the software, the three angles are determined from the test using the relation:

$$\mathbf{a_i = C_i\,(d_i - S_i\,)}$$

where: a_i = one of the three pot angles
d_i = voltage data corresponding to the pot
C_i = calibration factor for converting from voltage to engineering units
S_i = Setup = voltage corresponding to the pot set at zero degrees

The d_i corresponding to the initial data value during the start of the test would then produce the initial pot angle a_i .

If the initial voltage is set to zero by the data acquisition system, then a knowledge of the initial angle is required by other means. In this case the angle would be given by:

$$\mathbf{a_i = C_i (d_i + I_i - S_i)}$$

where: I_i = initial angle of pot

If the output from each pot has been converted to engineering units (degrees), the value of $\mathbf{C_i}$ = 1.

Appendix B: Procedure for Calculating Deflections from DGSP Measurements

The procedure for calculating the x, y, z displacements for the DGSPs is relatively straightforward. The geometric length of the rotating tube is measured from the center of the axis of the outer potentiometer which measures the rotation in the vertical plane. The outer yoke, which controls the up and down rotation will determine the plane in which the left-right rotation will take place.

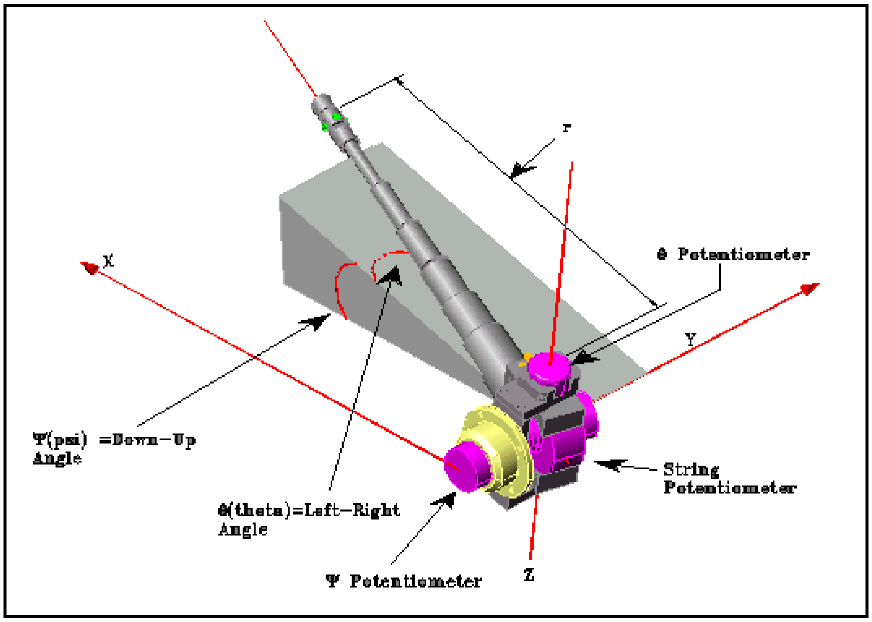

Figure B.1 Calculations for DGSP displacements.

If:

r = length of tube at given time
θ = angle measuring left-right angle
ψ = angle measuring down-up angle

Then the x, y, and z components at any time is given by:

$$
\begin{aligned}
x &= r \cos\theta \, \cos\psi \\
y &= r \sin\theta \\
z &= r \cos\theta \, \sin\psi
\end{aligned}
\tag{1}
$$

and the deflections are given by:

$$\Delta x = x - x_0$$
$$\Delta y = y - y_0$$

$$\Delta z = z - z_0$$

where, x_0 , y_0, z_0 are the components at the initial time.

The calculations for the left and right DGSPs are carried out in the same way, since their coordinate systems are identical, only the origin being shifted laterally. As in the case of the CRUX units, the conversion from voltage (or microstrain) to engineering units is accomplished by the relation:

$$a = C(d - S)$$

where:
- a = stringpot or rotary pot measurement
- C = calibration factor for converting from voltage to eng. units
- d = voltage measured at given time
- S = voltage corresponding to calibration setup value of unit

If the initial voltage is set to zero, then an initial length is required for the stringpot and initial angles required for the rotary pots. In this case the engineering value is given by:

$$a = C(d + I - S);$$ where I is the initial value of the sensor.

The signs used with the calibration factors convert the actual potentiometer angles into angles measured in the local abdomen frame. The local frame is defined by an X axis pointing to the front along the center line of the lower abdomen bracket; the Y axis pointing to the right; and the Z axis pointing down.

Appendix C: Procedure for Calculating Head Loads at the Occipital Condyle from Neck Load Cell Measurements

The procedure for computing the net force and moment acting on the head at the occipital condyle (O.C.) based on the forces seen at the neck load cell and the neck springs is given below. It is assumed that the inertial terms arising from the linear and angular accelerations of the segment of the neck between the O.C. and the center of the neck load cell (which is taken to be the point where measurement is made) is small and can be neglected. The various parts of the neck that enter into the calculation are shown in the following figure.

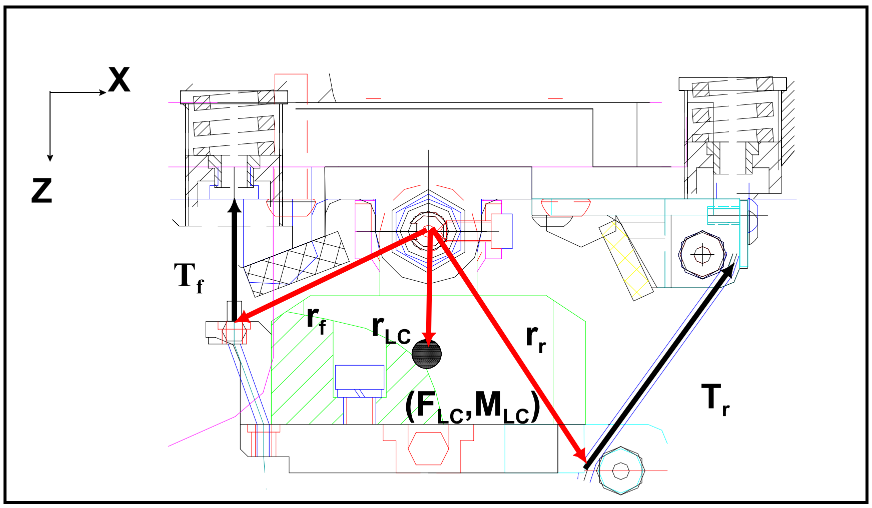

Figure C.1 Definition of terms used in equation for computing neck moments.

The reaction forces and moments acting on the head due to the neck at the O.C. are given in vector form by the equations:

$$\mathbf{F_H = -(F_{LC} + T_r + T_f)} \tag{1}$$

$$\mathbf{M_H = -(M_{LC} + r_{LC}{\times}F_{LC} + r_r{\times}T_r + r_f{\times}T_f)} \tag{2}$$

where: $\mathbf{F_H}$ = force acting on head at O.C.
$\mathbf{M_H}$ = moment acting on head at O.C.
$\mathbf{F_{LC}}$ = force measured at upper neck load cell
$\mathbf{M_{LC}}$ = moment measured at upper neck load cell
$\mathbf{T_r}$ = tension force acting along rear neck cable
$\mathbf{T_f}$ = tension force acting along front neck cable
$\mathbf{r_{LC}}$ = location of upper neck load cell center relative to O.C.
$\mathbf{r_r}$ = location of point on rear neck cable relative to O.C.
$\mathbf{r_f}$ = location of point on front neck cable relative to O.C.

We also require:

θ = angle between head and neck as measured at O.C.

Note: All position measurements for the head/neck assembly relative to the O.C. are made in the local SAE coordinate system.

All calculations are made in the local system of the head. The knowledge of the relative angle θ allows one to transform the forces and moments in the neck system to that in the head system using the transformation rule:

$$\mathbf{F}^{(h)}_{LC} = \mathbf{T}_{nh}\, \mathbf{F}^{(n)}_{LC} \tag{3}$$

where: $\mathbf{T}_{nh}$ = transformation between the neck to the head coordinate system. In terms of coordinates, this equation would be of the form:

$$\begin{pmatrix} F^{h}_{x} \\ F^{h}_{y} \\ F^{h}_{z} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} F^{n}_{x} \\ F^{n}_{y} \\ F^{n}_{z} \end{pmatrix} \tag{4}$$

The vector force representing the tension force along the rear cable is given by:

$$\mathbf{T_r} = \mathrm{T_r}\, \mathbf{n_r} \tag{5}$$

$$\mathbf{n_r} = \frac{(\mathbf{r}^1 - \mathbf{r}^2)}{|\mathbf{r}^1 - \mathbf{r}^2|}$$

where: $\mathrm{T_r}$ = magnitude of tension in rear cable (measured by spring load cell)

$\mathbf{n_r}$ = unit vector along cable direction

$\mathbf{r}^1$ = location of top end of cable (in head system)

$\mathbf{r}^2$ = location of bottom end of cable (in head system)

The line of action of the tension forces along the rear cable can be estimated from the locations of the top pulley (attached to the head) and the lower pulley (attached to the top of the neck). The location on the neck is transformed to the head coordinate system by the same transformation matrix, $\mathbf{T}_{nh}$.

For the tension force along the front cable, the line of action is computed in a similar way.

Appendix D: Procedure for Calculating Forces and Moments at the Ankle from Lower Tibia Measurements

The procedure for computing the force and the moment acting at the ankle joint based on the measurements at the lower tibia load cell and the tibia accelerometers is described below. It is assumed that the inertial terms arising from angular accelerations of the lower tibia segment can be ignored. The components of the lower tibia and ankle that are used in the analysis are shown in the figures below.

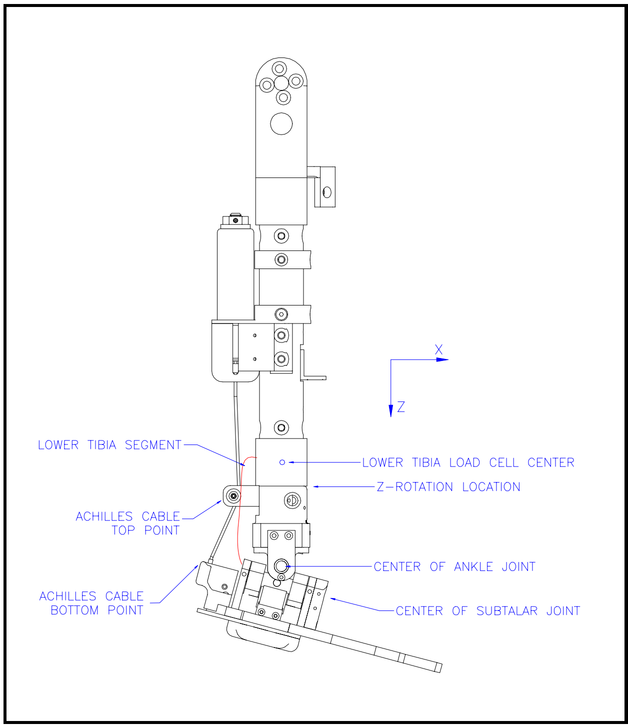

Figure D.1 Components of lower tibia and ankle system

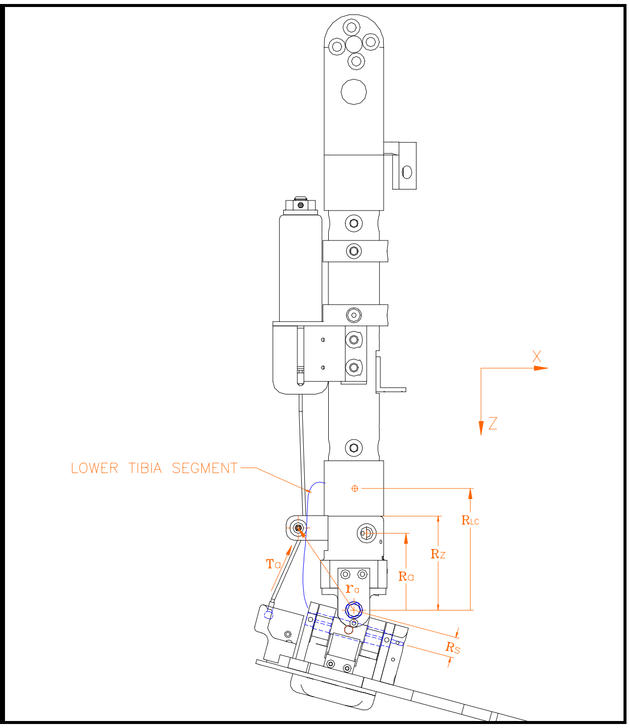

Figure D.2 Locations of components used in ankle moment computation

The force acting at the ankle joint is given by:

$$\mathbf{F}_{ank} = \mathbf{F}_{lc} + m_{ltib}\mathbf{a}_{ltib} \tag{1}$$

where:

$\mathbf{F}_{ank}$ = Force acting at ankle on lower tibia
$\mathbf{F}_{lc}$ = Force measured by lower tibia load cell
m_{ltib} = mass of lower tibia segment
$\mathbf{a}_{ltib}$ = acceleration measured at the C.G. of the lower tibia

The second term in the above equation corresponds to the inertia of the lower tibia segment. It is assumed that the dominant motion is translational and any angular motion is limited. In this case, the actual position of the accelerometer is not considered, and it is assumed that the accelerometer reading is a fair representation of the motion of the C.G. of the lower tibia segment. This may not hold true in situations where the tibia is rotating rapidly relative to the femur.

The moment acting at the ankle on the lower tibia is:

$$\mathbf{M}_{ank} = \mathbf{M}_{lc} + \mathbf{r}_{lc} \times \mathbf{F}_{lc} + \mathbf{r}_{\mathbf{a}} \times m_{ltib}\mathbf{a}_{ltib} \tag{2}$$

where:
$\mathbf{M}_{ank}$ = Moment acting at ankle on lower tibia
$\mathbf{M}_{lc}$ = Moment measured by lower tibia load cell
$\mathbf{r}_{lc}$ = vector position of center of load cell relative to ankle joint
$\mathbf{r}_{a}$ = vector position of C.G. of lower tibia segment relative to ankle joint

Note: All position measurements for the leg or foot relative to the ankle are made in the local SAE coordinate system. Thus the location of the lower tibia load cell which is proximal to the ankle will have a negative Z coordinate relative to the ankle, while the location of the subtalar joint will have a positive Z coordinate.

If there is rotation about the Z, in the Thor-Lx, the force and moment as measured in the load cell coordinate system is transformed to the ankle system.. This implies that the X and Y components of $\mathbf{F}_{lc}$ and $\mathbf{M}_{lc}$ and have to be transformed by the relations:

$$\begin{aligned} F'_{lc} &= R_z\, F_{lc} \\ M'_{lc} &= R_z\, M_{lc} \\ a'_{ltib} &= R_z\, a_{ltib} \end{aligned} \tag{3}$$

where:

F'_{lc} = Force in rotated ankle system
M'_{lc} = Moment in rotated ankle system
a'_{ltib} = Lower tibia acceleration in ankle system

$$R_z = \begin{bmatrix} \cos\theta_z & \sin\theta_z & 0 \\ -\sin\theta_z & \cos\theta_z & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

θ_z = rotation angle of foot about Z-axis

In component form, this would mean:

$$\begin{aligned} F'^{x}_{lc} &= F^{x}_{lc}\cos\theta_z + F^{y}_{lc}\sin\theta_z \\ F'^{y}_{lc} &= -F^{x}_{lc}\sin\theta_z + F^{y}_{lc}\cos\theta_z \end{aligned} \tag{5}$$

Similar relations will hold for the moment and acceleration. It is assumed in these situations, M^z and a^z are zero or can be neglected.

If we consider the forces and moment in the X-Z plane, i.e. for dorsiflexion, equations (1) and (2) become:

$$\begin{aligned} F_{ank}^{\ x} &= F'^{x}_{lc} + m_{ltib} a'^{x}_{ltib} \\ M^{y}_{ank} &= M'^{y}_{lc} + (z_{lc} F'^{x}_{lc} - x_{lc} F'^{z}_{lc}) + (z_a m_{ltib} a'^{x}_{ltib} - x_a m_{ltib} a'^{z}_{ltib}) \end{aligned} \tag{6}$$

In the leg/ankle system of Thor, the location of the lower tibia load cell center and the C.G. of the lower tibia segment, and the ankle joint are all along the local Z-axis of the tibia. In this case, the equations simplify to:

$$\begin{aligned} F_{ank}^{\ x} &= F'^{x}_{lc} + m_{ltib} a'^{x}_{ltib} \\ M^{y}_{ank} &= M'^{y}_{lc} + z_{lc} F'^{x}_{lc} + z_a m_{ltib} a'^{x}_{ltib} \end{aligned} \tag{7}$$

A similar set of equations are defined for the moment at the subtalar joint responsible for inversion/eversion (rotation about X axis).

$$\mathbf{F}_{sub} = \mathbf{F}_{lc} + m_{ltib}\mathbf{a}_{ltib} \tag{8}$$

$$\mathbf{M}_{sub} = \mathbf{M}_{lc} + \mathbf{r}_{lcs} \times \mathbf{F}_{lc} + \mathbf{r}_{as} \times m_{ltib}\mathbf{a}_{ltib}$$

where:

$\mathbf{F}_{sub}$ = Force acting at subtalar joint on lower tibia
$\mathbf{M}_{ank}$ = Moment acting at subtalar joint on lower tibia
$\mathbf{r}_{lcs}$ = vector position of center of load cell relative to subtalar joint
$\mathbf{e}_{as}$ = vector position of C.G. of lower tibia segment relative to subtalar joint

In the above relations, we neglect the inertial effect of the small mass element associated with the ankle block. In order compute the moment at the subtalar joint, it is necessary to transform the forces and moments measured at the lower tibia load cell through two coordinate system rotations. The first is the rotation about the Z-axis, as given by the equations (3). The second is a rotation about th Y-axis due to the dorsiflexion at the ankle joint. In this case, the transformation equations are given by:

$$\begin{aligned} F''_{lc} &= R_y\, F'_{lc} \\ M''_{lc} &= R_y\, M'_{lc} \\ a''_{ltib} &= R_y\, a'_{ltib} \end{aligned} \tag{9}$$

where:

F''_{lc} = Force in rotated ankle system
M''_{lc} = Moment in rotated ankle system
a''_{ltib} = Lower tibia acceleration in ankle system

$$R_y = \begin{bmatrix} \cos\theta_y & 0 & -\sin\theta_y \\ 0 & 1 & 0 \\ \sin\theta_y & 0 & \cos\theta_y \end{bmatrix} \tag{10}$$

θ_y = rotation angle of foot about Y-axis

In component form, this would mean:

$$\begin{aligned} F''^{x}_{lc} &= F'^{x}_{lc}\cos\theta_y - F'^{z}_{lc}\sin\theta_y \\ F''^{z}_{lc} &= F'^{x}_{lc}\sin\theta_y + F'^{z}_{lc}\cos\theta_y \end{aligned} \tag{11}$$

Similar relations will hold for the moment and acceleration. For the latter quantities, it is assumed in these situations, M^z and a^z are zero or can be neglected.

If we consider the forces and moment in the X-Z plane, i.e. for dorsiflexion, equation (8) becomes:

$$\begin{aligned} F^{y}_{sub} &= F''^{y}_{lc} + m_{ltib}a''^{y}_{ltib} \\ M^{x}_{sub} &= M''^{x}_{lc} + (y_{lcs}F''^{z}_{lc} - z_{lcs}F''^{y}_{lc}) + (y_{as}m_{ltib}a''^{z}_{ltib} - z_{as}m_{ltib}a''^{y}_{ltib}) \end{aligned} \tag{12}$$

In the leg/ankle system of Thor, the location of the lower tibia load cell center and the C.G. of the lower tibia segment, and the subtalar joint are all along the local Z-axis of the tibia. In this case, the equations simplify to:

$$\begin{aligned} F_{sub}{}^{y} &= F''^{y}_{lc} + m_{ltib}a''^{y}_{ltib} \\ M^{x}_{sub} &= M''^{x}_{lc} - z_{lcs}F''^{y}_{lc} - z_{as}m_{ltib}a''^{y}_{ltib} \end{aligned} \tag{13}$$

Equations (7) and (13) are used for determining the dorsiflexion/plantarflexion and inversion/eversion torques.

NOTE:	**The equations in (13) do not include the components M^z and a^a and imply that they can be neglected.**

If the Achilles tension is being measured, then the program computes one additional moment, i.e. the total dorsiflexion moment through the cross-section of the whole lower leg at the level of the ankle and includes the force and moment generated by the Achilles cable on the lower tibia.

The vector force representing the tension force along the rear cable is given by:

$$\mathbf{T_A} = \mathrm{T_A}\,\mathbf{n_A} \tag{14}$$

$$\mathbf{n_A} = \frac{(\mathbf{r^t} - \mathbf{r^b})}{|\mathbf{r^t} - \mathbf{r^b}|}$$

where: T_A = magnitude of tension in Achilles cable (measured by spring load cell)
$\mathbf{n_A}$ = unit vector along cable direction
$\mathbf{r^t}$ = location of top end of cable (in lower tibia system)
$\mathbf{r^b}$ = location of bottom end of cable (in lower tibia system)

The line of action of the tension forces along the Achilles cable can be estimated from the locations of the pulley (attached to the lower tibia) and the foot mounting post (attached to the rear of the foot). The location on the foot is transformed to the ankle coordinate system by the transformation matrix, R_x.

where:

$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_x & \sin\theta_x \\ 0 & -\sin\theta_x & \cos\theta_x \end{bmatrix}$$

θ_x = rotation angle of foot about X-axis

and:

$$\mathbf{r^t}_{(ank)} = \mathbf{R_y}\,\mathbf{R_x}.\mathbf{r^t}_{(foot)}$$

where:
$\mathbf{R_y}$ = rotation matrix given in equation (10)
$\mathbf{r^t}_{(foot)}$ = bottom cable location in foot coordinate system
$\mathbf{r^t}_{(ank)}$ = bottom cable location in ankle coordinate system

The moment due to the Achilles force is then given by:

$$\mathbf{M}_A = \mathbf{r}^t \times \mathbf{T}_A$$

Using the total section moment at the ankle is then given by:

$$\mathbf{M}_{sec} = \mathbf{M}_{ank} + \mathbf{M}_A$$